



Epipalaeolithic occupation and palaeoenvironments of the southern Nefud desert, Saudi Arabia, during the Terminal Pleistocene and Early Holocene

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ABSTRACT

The transition from the Terminal Pleistocene to the Early Holocene is poorly represented in the geological and archaeological records of northern Arabia, and the climatic conditions that prevailed in the region during that period are unclear. Here, we present a new record from the site of Al-Rabyah, in the Jubbah basin (southern Nefud desert, Saudi Arabia), where a sequence of fossiliferous lacustrine and palustrine deposits containing an archaeological assemblage is preserved. Sedimentological and palaeoenvironmental investigations, both at Al-Rabyah and elsewhere in the Jubbah area, indicate phases of humid conditions, during which shallow lakes developed in the basin, separated by drier periods. At Al-Rabyah, the end of a Terminal Pleistocene phase of lake expansion has been dated to ~12.2 ka using optically stimulated luminescence (OSL), with a mid-Holocene humid phase dated to after ~6.6 ka. Palaeoecological reconstructions based primarily on non-marine molluscs and ostracods from the younger lacustrine deposits indicate a relatively shallow body of freshwater surrounded by moist, well-vegetated environments. A lithic assemblage characterized by bladelets and geometric microliths was excavated from sediments attributed to a drier climatic phase dated to ~10.1 ka. The lithic artefact types exhibit similarities to Epipalaeolithic industries of the Levant, and their occurrence well beyond the 'core region' of such assemblages (and at a significantly later date) has important implications for understanding interactions between Levantine and Arabian populations during the Terminal Pleistocene–Early Holocene. We suggest that the presence of foraging populations in the southern Nefud during periods of drier climate is due to the prolonged presence of a freshwater oasis in the Jubbah Basin during the Terminal Pleistocene–Early Holocene, which enabled them to subsist in the region when neighbouring areas of northern Arabia and the Levant were increasingly hostile.

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1. Introduction

Previous research in the southern Nefud has identified archaeological assemblages of both Middle Palaeolithic and Neolithic age. The former, characterised by Levallois stone tool technologies, have

been dated to humid periods during Marine Isotope Stages (MIS) 7 and 5 (Petraglia et al., 2012). Neolithic assemblages similar to the Pre-Pottery Neolithic (PPNA and PPNB), recovered from the surface, have been assigned an age of ~9–8 ka, inferred from proximal Holocene sequences (Crassard et al., 2013). This repeated occupation of the region highlights its importance to human populations over a long period of time, but until now very little evidence for occupation during the intervening period, encompassing the transition from the Pleistocene to the Holocene, has been

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forthcoming (cf. Maher, 2009). The recovery of a lithic assemblage with affinities to the Levantine Epipalaeolithic (EP) from a dated sequence at Al-Rabyah, in the Jubbah basin, has therefore provided an important opportunity to examine human responses to climatically driven landscape change in the southern Nefud at that time.

The Levantine EP is dated to between c. 24 and 11.8 ka and is characterized by a diverse range of lithic industries accompanied by a variety of bone tools, body ornaments, mobile art and other cultural expressions (e.g. Bar-Yosef, 1970; Henry, 1982; Goring-Morris, 1995; Goring-Morris and Belfer-Cohen, 1997; Shea, 2013). EP lithic assemblages are typified by blade and bladelet production, based on pyramidal single platform cores. Blanks are further transformed into microliths, which show great morphological and regional variability through time (e.g. Henry, 1988; Neeley and Barton, 1994; Goring-Morris, 1995; Barton and Neeley, 1996; Belfer-Cohen and Goring-Morris, 2002; Maher et al., 2012; Shea, 2013). The core region for the Levantine EP encompasses the Sinai Peninsula, the eastern Mediterranean and Iraq, with the majority of important sites located in the central part of this region (cf. Shea, 2013). There are also many general similarities between the Levantine EP and lithic assemblages of roughly equivalent age in Mediterranean North Africa, the Nile Valley and montane western Asia (Kozłowski, 1999; Garcea, 2010; Schild and Wendorf, 2010; Düring, 2011; Shea, 2013). In the Arabian Peninsula, evidence for the presence of post-Middle Palaeolithic human groups prior to the Neolithic has so far only been found at a handful of sites in northern and central-southern Saudi Arabia (cf. Maher, 2009; Groucutt and Petraglia, 2012) and in southern Oman (Rose and Usik, 2009; Hilbert, 2014), although the assemblages from the latter exhibit few similarities with the Levantine EP and are instead more characteristic of local lithic industries. This technological and spatial disconnect between the core area of EP industries in the Levant and those from southern Arabia highlights the paucity of sites that can be reliably attributed to this period across much of the Arabian interior, and the resulting lack of understanding of the Terminal Pleistocene–Early Holocene in Arabia.

The apparent absence of Late Pleistocene–Early Holocene sites in the Arabian Peninsula has been attributed to the harsh, arid environmental conditions that prevailed across much of the region during the last glacial period, making Pre-Neolithic human incursions into the interior extremely difficult (e.g. Uerpmann et al., 2009; Bretzke et al., 2013). Although it is reasonable to assume that the timing of any demographic expansions into the Arabian desert belt would have coincided with periods of increasingly humid climate, it is important to consider the spatial and temporal variability of these climatic phases across Arabia during the Terminal Pleistocene–Early Holocene. Palaeoclimatic evidence from the Levant suggests that the Early Holocene period remained relatively dry (e.g. Vaks et al., 2010; Enzel et al., 2008; Petit-Maire et al., 2010), whereas regions of Yemen and southern Oman, located closer to the Intertropical Convergence Zone (ITCZ) and associated monsoon rain belt, became increasingly humid at ~11 ka (Radies et al., 2005; Davies, 2006; Lézine et al., 2007; Fleitmann et al., 2007). It has therefore been suggested that the onset of wetter conditions occurred earlier in southern Arabia than in the central desert regions (Parker, 2009). To the north, in the southern Nefud desert, Holocene lake formation has been dated to ~10 ka (Whitney and Gettings, 1982; Whitney, 1983; Whitney et al., 1983; Engel et al., 2012). Most recently, evidence from a locality at Jebel Qatar (JQ-200) has indicated humid conditions in the Jubbah basin between ~9 and 8 ka (Crassard et al., 2013). These findings are at odds with a broader analysis of the timing of late Quaternary lake formation across the Nefud (Rosenberg et al., 2013), which reported no Holocene lake formation; similarly, no

evidence for lake formation during the Early Holocene has been reported from neighbouring regions such as Jordan (Petit-Maire et al., 2010; Cordova et al., 2013).

These contradictions illustrate the complexity of the climatic and environmental conditions that prevailed in northern Arabia at the Pleistocene–Holocene transition. Not only are significant differences in the timing of humid conditions apparent, but also variations in regional responses to increased rainfall, driven primarily by geomorphology. These have important implications for the availability of food and water supplies across northern Arabia, which are in turn critical to understanding the demographic complexity of the period. The Al-Rabyah site represents the first well-dated sequence from which archaeological and palaeoenvironmental evidence can be integrated, and contributes to a growing corpus of data suggesting that the Jubbah basin was a critical freshwater oasis in the southern Nefud during the transition from the Terminal Pleistocene to the Early Holocene.

2. Site location and description

The site of Al-Rabyah is located at the western end of a large basin near the town of Jubbah, in the southern Nefud desert of northern Saudi Arabia (Fig. 1). The area is bounded to the north and south by extensive fields of barchan dunes, some of which attain heights of up to 60 m, and to the east and west by a belt of sandstone jebels. The site is situated approximately 300 m from the eastern flank of Jebel Umm Sanman (Fig. 2), which attains a height of ~400 m above the basin floor and has sheltered the adjacent basin from infilling by the eastward transport of aeolian material. Consequently, preserved Terminal Pleistocene–Early Holocene sediment sequences are exposed across the basin floor.

The site is one of several mounds of lacustrine and palustrine sediments, predominantly marls and silty sands, capped by highly indurated calcretes. These crop out up to ~2 m above the surrounding partially deflated land surface, which dips gently to the SSW and is primarily composed of pale, fine–medium aeolian sands of mixed lithologies and iron-rich quartzitic coarse sands. The cemented calcrete capping the Al-Rabyah mound has protected a sequence of 16 sedimentary units (Fig. 2), one of which preserved a stratified archaeological assemblage. Similar inverted relief features armoured by calcrete crusts have been observed in other arid regions, such as Egypt (Aref, 2003) and Kuwait (Al Shuaibi and Khalaf, 2011).

Archaeological material was also found scattered over a discrete area of the deflated surface in the vicinity of the Al-Rabyah mound. Importantly, no archaeological material could be found on top of this feature. This, taken together with typological similarities to the excavated material, indicates that the surface artefacts were eroded from lateral extensions of the preserved deposits (Fig. 1). Similar situations have been observed elsewhere in the southern Nefud, such as at the Middle Palaeolithic site at Jebel Katefeh (Petraglia et al., 2012).

3. Materials and methods

3.1. Excavation

An 8 m long trench was excavated by hand in the Al-Rabyah mound, exposing *in situ* sediments to a depth of 2.5 m. Sediment removed from the trench was sieved through a 3 mm mesh to ensure full recovery of smaller artefacts. Surface collections of lithic material were also undertaken, covering an area of ~500 m² (Fig. 1). Samples were taken from the exposed sections for dating and palaeoenvironmental analyses (see below).

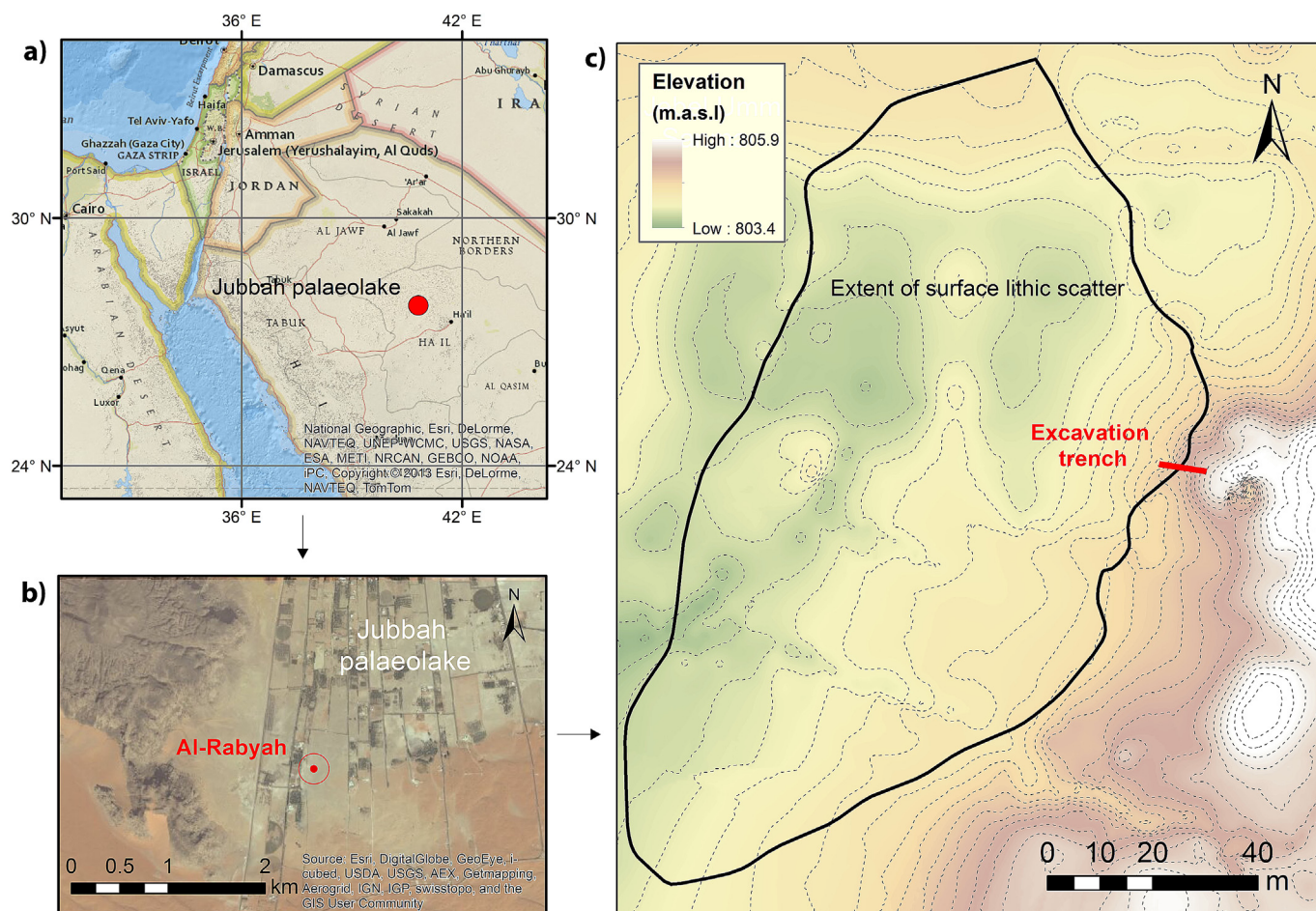


Fig. 1. Maps showing the location of Al-Rabyah: a) regional situation showing location of the Jubbah basin in the southern Nejd desert, north-central Saudi Arabia; b) location of the Al-Rabyah site; c) topographic survey of the site, showing the extent of the surface lithic scatter outlined in black and the location of the excavated trench in red. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.2. Optically stimulated luminescence dating

Four tube samples (ARY-OSL1, 2, 3 and 7), together with accompanying water content samples, taken from Units 3, 7 and 8 exposed in the cleaned north-facing section (Fig. 2). Samples were collected by hammering lengths of opaque PVC pipe (c. 5–6 cm diameter × 20 cm long) into the section and capping the ends for transport. Processing was conducted under subdued LED lighting (590 nm) at the Research Laboratory for Archaeology and the History of Art, University of Oxford. Coarse grain quartz (180–255 μm) was extracted following the procedures outlined in Clark-Balzan et al. (2012), with the addition of a sodium polytungstate density separation procedure (retained $\rho > 2.58 \text{ g cm}^{-3}$) between the hydrochloric acid digestion and hydrofluoric acid etching stages. All OSL measurements were made with a Risø TL/OSL DA-15 Minisys, which incorporates a $^{90}\text{Sr}/^{90}\text{Y}$ beta source and an LED stimulation unit comprising NISHIA blue LEDs (NSPB-500S, 470Δ20 nm) and infrared LEDs (875 nm, 135 m Wcm $^{-2}$) (Bøtter-Jensen et al., 2000, 2003). Stimulation light was removed by green long pass filters (GG-420) attached to the blue LEDs and a 7.5 mm Hoya U-340 bandpass filter, whilst UV emissions were detected with an EMI Electronics photo-multiplier tube (9235/0158/19747.0020).

Between 15 and 20 multigrain aliquots were measured from each sample, depending on the proportion rejected. Samples ARY-OSL1 and ARY-OSL2, collected from Unit 8, were measured as 5–6 mm aliquots, whereas ARY-OSL3 and ARY-OSL7, from Units 3

and 7 respectively, were measured as 1–2 mm aliquots in order to detect any partial bleaching. A single aliquot regeneration protocol (Murray and Wintle, 2000) was used which incorporated a hot bleach at the end of each cycle (blue LEDs, 280 °C for 100 s). After all necessary regeneration dose points, zero dose, recycling ratio, and IR depletion steps (100 s stimulation at 50 °C; Duller et al. 2003) were given. Preheats were 240 °C (dose) and 220 °C (regeneration) for 10 s, and blue optical stimulation occurred for 60 s at 125 °C. A dose recovery experiment was performed for sample ARY-OSL2 (Fig. 3). Eight multigrain aliquots (5 mm) were bleached with Mini-sys blue LEDs for 300 s at 25 °C then irradiated with approximately the expected equivalent dose ($12.4 \pm 0.2 \text{ Gy}$).

Data analysis was performed with Luminescence Analyst v 4.11. The first 1.20 s and last 12.24 s were used to determine the signal and background, respectively. An extra 2% uncertainty was included to account for random experimental and calibration errors, and equivalent dose errors were determined via 2000 Monte Carlo cycles. Aliquots were excluded from analysis if any of the following acceptance criteria were not met: test dose error less than 15% of test signal, recycling ratio within 10% of unity or indistinguishable from unity at 2 sigma error, zero ratio less than 5% or indistinguishable from 0 at 2 sigma error, IR depletion ratio greater than 90% or indistinguishable from unity at 2 sigma error. The central age model or minimum age models were used to calculate each sample's equivalent dose from all accepted aliquots (see later discussion).

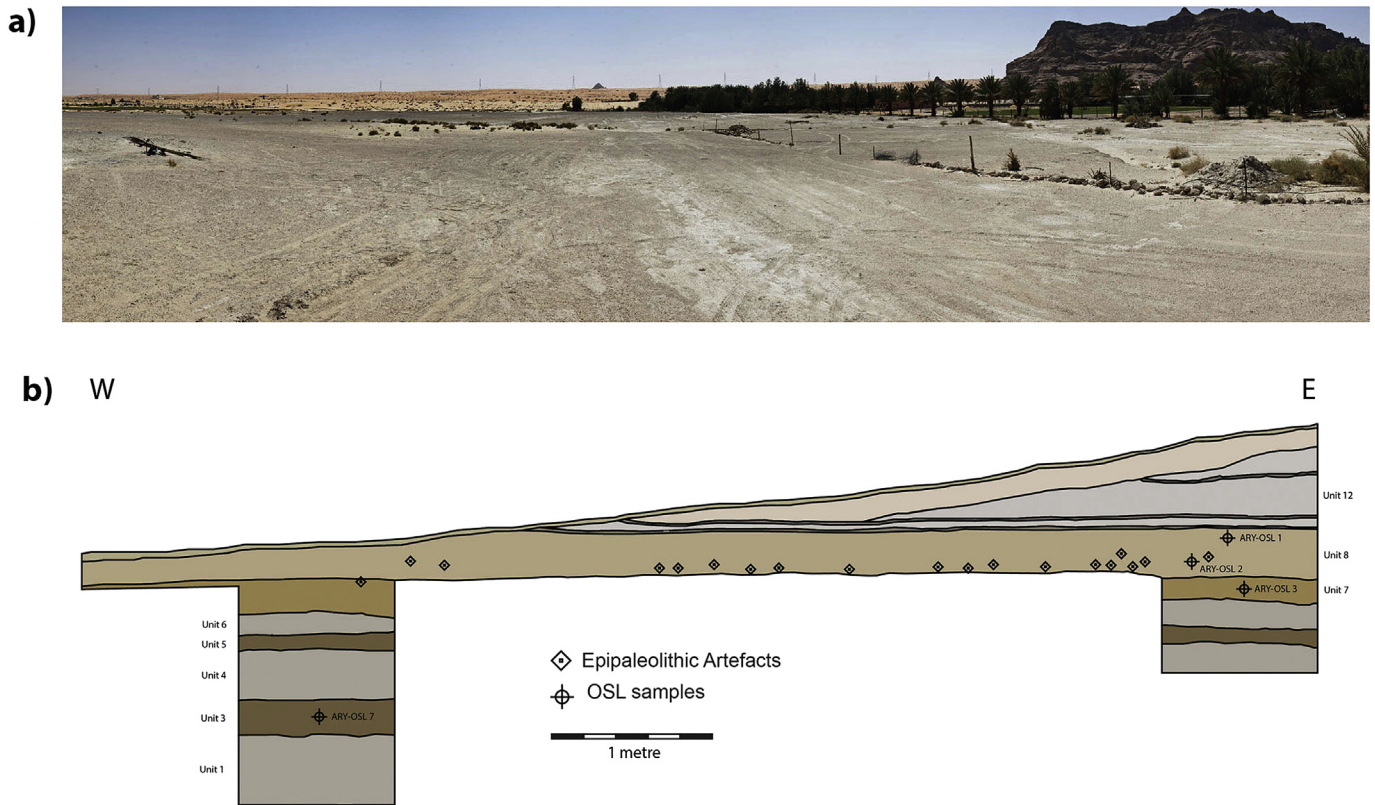


Fig. 2. a) photograph of the site looking towards the south-east; b) north section of the Al-Rabyah trench, showing positions of excavated EP artefacts, OSL samples and general configuration of stratigraphic units.

Beta dose rates were calculated from elemental concentrations derived from ICP analysis via [Adamiec and Aitken's \(1998\)](#) conversion and [Mejdahl's \(1979\)](#) attenuation values. A Canberra Inspector 1000 gamma spectrometer was used to measure *in situ*

gamma dose rates for each sample, which were calculated using the threshold technique ([Mercier and Falguères, 2007](#); [Duval and Arnold, 2013](#)). This instrument was calibrated against measurements from the doped concrete blocks at the University of Oxford

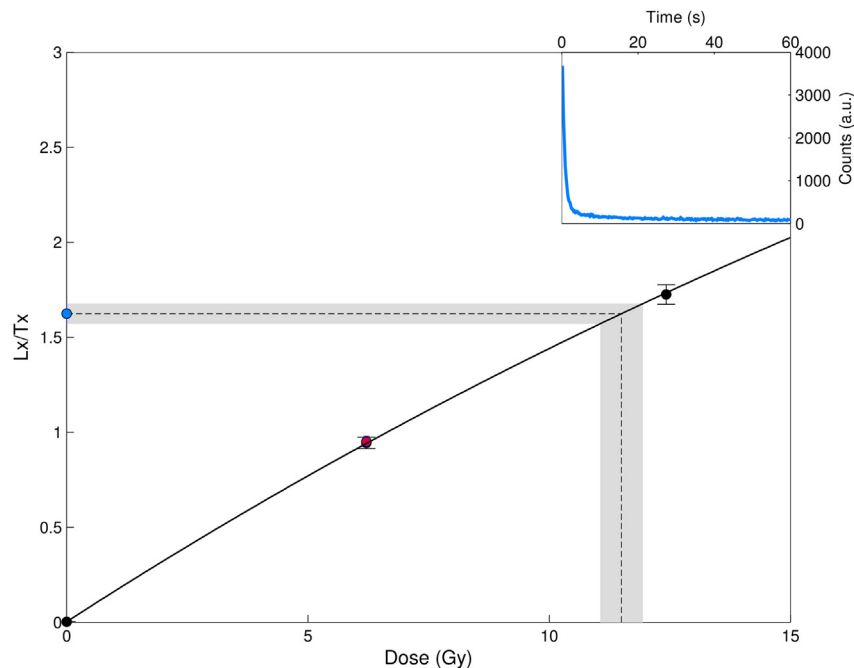


Fig. 3. Dose response curve and OSL decay curve (inset) for a representative aliquot from sample ARY-OSL2. The 6.2 Gy regeneration point used to calculate the recycling ratio (1.01 ± 0.04) and the IR depletion ratio (0.99 ± 0.04) are shown in this plot, but cannot be distinguished due to marker overlap.

(Rhodes and Schwenninger, 2007). An average water content of $5 \pm 3\%$ was assumed, in order to account for variations in moisture content over time. All samples contained less than 1% water by mass of wet sediment at the time of sampling. Cosmic dose rates were calculated assuming current depths and an average overburden density of 1.9 g cm^{-3} (Prescott and Stephan, 1982; Prescott and Hutton, 1988, 1994). The alpha dose rate was assumed to be negligible.

The recovered dose (mean of accepted aliquots) was within 5% of the laboratory administered dose, indicating acceptable performance of the measurement protocol (Table 1). Rejection criteria for equivalent dose measurements also indicate good SAR performance for the majority of measured aliquots. It should be noted that rejection of multigrain aliquots due to test dose error magnitude is rare, but might be expected for small aliquots (40–50 grains) from the Arabian peninsula based on known single grain characteristics (Petruglia et al., 2012).

Based on site characteristics, the most likely process to cause any OSL age inaccuracy is partial bleaching of lacustrine units. Visual inspection of the stratigraphy in the field suggested that physical mixing of coarse grains between sedimentary units was unlikely after deposition. Both carbonate-rich marls and coarse sand units are horizontally bedded with clear, defined boundaries. It is also highly unlikely that samples ARY-OSL1 and OSL2, which were predominantly deposited by aeolian processes, would suffer from partial bleaching. Comparison of range and asymmetry for the small aliquot equivalent dose distributions of lacustrine-deposited samples ARY-OSL3 and ARY-OSL4 suggests that bleaching conditions were adequate for ARY-OSL3. ARY-OSL4, however, yielded the most asymmetric and scattered distribution (Fig. 4), for which the most parsimonious explanation seems to be partial bleaching (Olley et al., 1998; Arnold et al., 2007). Therefore, a 3-component minimum age model ($\sigma = 20\%$) was used to calculate the final age. The use of the minimum age model should yield an accurate final age in this case due to the use of small aliquots and the infrequency of bright grains in Arabian quartz (Arnold and Roberts, 2009). Model results also suggest that just over 70% of the aliquots were well-bleached. Ages for other samples were calculated based on an equivalent dose derived from the central age model.

3.3. Palaeoenvironmental sampling

Palaeoenvironmental samples were recovered at contiguous 5 cm intervals through the sequence. Loss on ignition organic (LOI_{org}) and carbonate content (LOI_{carb}) analyses were conducted following procedures outlined by Heiri et al. (2001), whilst magnetic susceptibility values were determined following the

procedure described by Dearing (1999). Granulometry was analysed using a Malvern Mastersizer 2000. The resulting dried residues were examined under a low-powered binocular microscope for fossil remains. In addition, bulk samples from the upper part of the sequence were recovered for more detailed palaeontological analysis. These were wet sieved through nested laboratory test sieves (minimum 500 μm mesh for molluscs and 125 μm mesh for ostracods). The resulting residues were air-dried and picked for fossil remains.

3.4. Artefact analysis

Morphometrical characteristics of the recovered lithic assemblage were studied, including: scar pattern, striking platform morphology, artefact morphology (midpoint and longitudinal cross sections), raw material and degree of patination.

4. Results

4.1. Stratigraphy and chronology

The oldest part of the Al-Rabyah sequence (Units 1 to 6; Fig. 5) records a phase of shallow lake formation, the uppermost part of which is dated to $12.2 \pm 1.1 \text{ ka}$ (Table 2). Variations in magnetic susceptibility, carbonate content and clay–silt content values in this part of the sequence could reflect changes in aridity, although they might also be due to seasonal changes, wind speed or single events such as sandstorms; influxes of iron-rich aeolian sand possibly signify drier periods (Fig. 5). A significant change in sedimentation occurred during deposition of Unit 7, dated to $11.4 \pm 0.8 \text{ ka}$, and Unit 8, from which two dates of $10.1 \pm 0.6 \text{ ka}$ and $6.6 \pm 0.7 \text{ ka}$ were obtained. Sharp decreases in carbonate and clay–silt values throughout these units might represent a phase of drier conditions, with an influx of coarse sands and a greater degree of sorting evident within Unit 8 (Fig. 5). However, the generally poorly-sorted and coarsely-skewed nature of these deposits, which are also iron-stained and contain numerous root voids, indicates that groundwater continued to play a significant role in sedimentation. We therefore suggest that Unit 8, which yielded the archaeological material, represents a wetter landscape within the Jubbah basin. A sharp peak in grain size in the middle of Unit 8 (Fig. 5) represents an influx of medium-coarse aeolian sand, indicating an abrupt increase in aridity. The earlier date from Unit 8 was obtained from this coarser material.

These deposits are overlain by a series of silts and fossiliferous marls (Units 9 to 15; Fig. 5), which become increasingly cemented up profile and contain numerous root voids and rhizoliths. This part

Table 1
Numbers of OSL aliquots excluded according to rejection criteria, and distribution parameters calculated for accepted aliquot populations. Equivalent doses in bold have been used for final age calculations (see SI for rejection criteria and age model discussion). The recycling ratio and zero dose ratio criteria have been reported as non-exclusive categories (i.e. some aliquots are counted in both categories). a) equivalent dose measurements; b) dose recovery experiment, with given and normalized recovered doses reported.

Sample	Meas. (#)	Number rejected				Accepted (#)	CAM D_e (Gy)	Overdispersion (%)	MAM D_e (Gy)
		Tx err	RR	Zero	IR				
a)									
ARY-OSL1	20	0	1	0	6	13	8.1 ± 0.8	36.2 ± 7.2	—
ARY-OSL2	15	0	1	0	2	12	12.6 ± 0.5	11.0 ± 2.9	—
ARY-OSL3	20	0	4	1	6	10	25.5 ± 1.3	13.4 ± 4.1	—
ARY-OSL7	20	1	0	0	7	12	37.4 ± 3.8	33.5 ± 7.3	33.0 ± 2.6
Sample	Meas. (#)	Number rejected				Accepted (#)	Given dose	Recovered D_e (normalized, mean $\pm 1\sigma$)	
		Tx err	RR	Zero	IR				
b)									
ARY-OSL2	8	0	0	0	2	6	12.4 ± 0.2	0.97 ± 0.15	

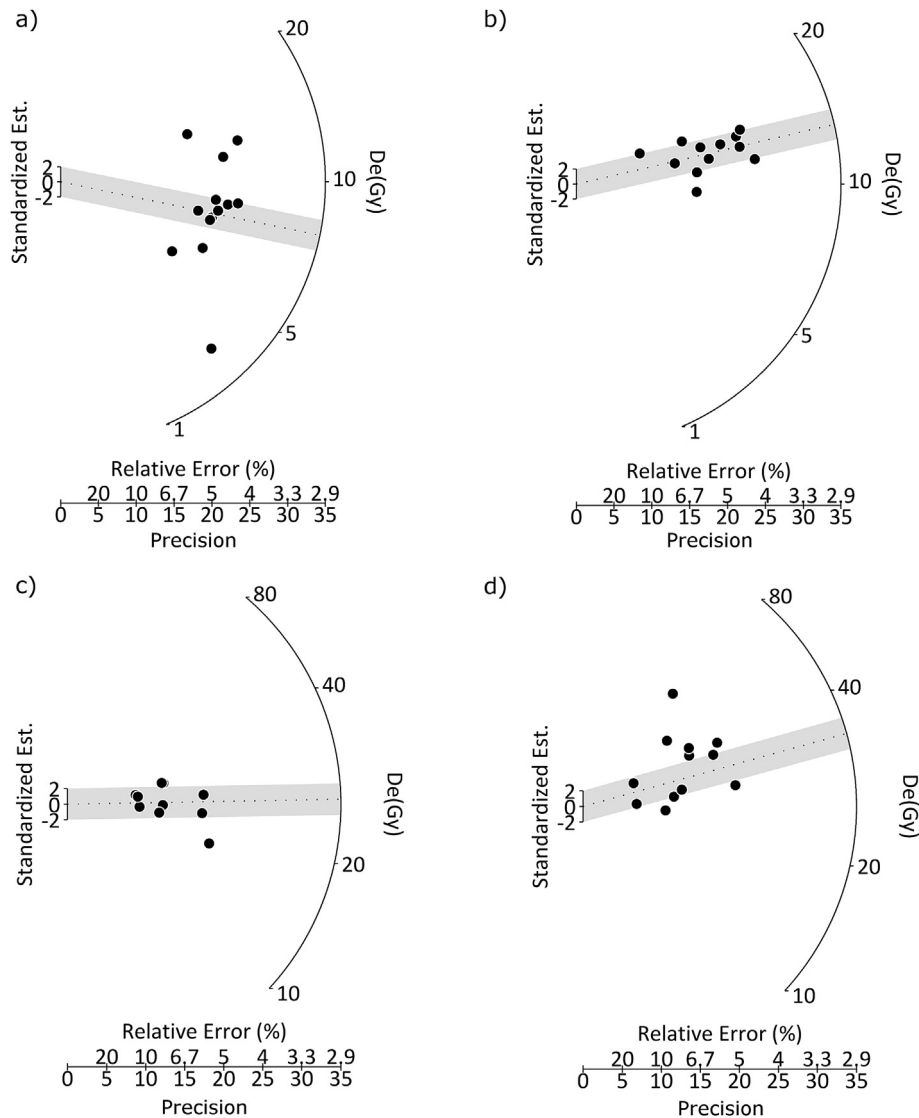


Fig. 4. Radial plots shown for measured and accepted multigrain aliquots: a) ARY-OSL1, b) ARY-OSL2, c) ARY-OSL3, d) ARY-OSL4. For a–c, the central age model equivalent dose (dotted line) and the 2σ vertical range (grey shading) are plotted. The minimum age equivalent dose is shown for d).

of the sequence represents a return to humid conditions at the site some time after 6.6 ± 0.7 ka. Palaeoenvironmental proxy data for these units indicate an initial sharp increase in organic carbon, carbonate and clay–silt content, with a corresponding decline in magnetic susceptibility values. Subsequent variations in these values indicate numerous fluctuations in the waterbody.

4.2. Palaeoecology

The basal marls (Units 1–6; 5) contained no fossils, although the sedimentary evidence described above suggests that they were deposited under lacustrine conditions. The artefact-bearing part of the sequence (Unit 8) was similarly poor in fossils, although again sedimentary evidence indicates a water-lain component. This, together with the presence of numerous root voids and rhizoliths, suggests a somewhat vegetated environment, and the presence of shallow waterbodies in the vicinity of the site cannot be ruled out.

The upper part of the sequence (Units 9–15; Fig. 5) contained well-preserved assemblages of non-marine molluscs, ostracods and charophytes. The aquatic molluscan fauna (Fig. 6, Table 3) is dominated by Lymnaeidae, although taxonomic uncertainties (cf.

Neubert, 1998) prevent identification to species level. Also present were subordinate numbers of *Gyraulus* sp; the taxonomy of *Gyraulus* species in Arabia is also unclear and requires revision (Neubert, 1998). However, on the basis of shell characters and microsculpture, the specimens recovered from Al-Rabyah most closely resemble *G. convexiusculus*. This species occurs in the modern Arabian freshwater fauna, but is presently only known from two oases in the Eastern Province (Neubert, 1998). A few specimens of *Hydrobia* cf. *lactea* were also recovered. This variable species is apparently widespread in eastern Arabia, occurring in freshwater ditches and irrigation channels (Brown and Wright, 1980; Brown and Gallagher, 1985; Neubert, 1998). Two species of land snail were also recorded: *Vertigo antivertigo* and an indeterminate succineid (Fig. 6). The former is characteristic of variety of wetland habitats, including fens and marshes, and is often present on lakeshores, where it can be found amongst saturated ground litter and amongst decaying reed stems (Kerney and Cameron, 1979; Hornung et al., 2003). Its distribution is widely stated as Palaearctic, although it might have a Holarctic range if similar North American species are found to be conspecific with *V. antivertigo* (Pokryszko et al., 2009). It is not part of the modern Arabian fauna

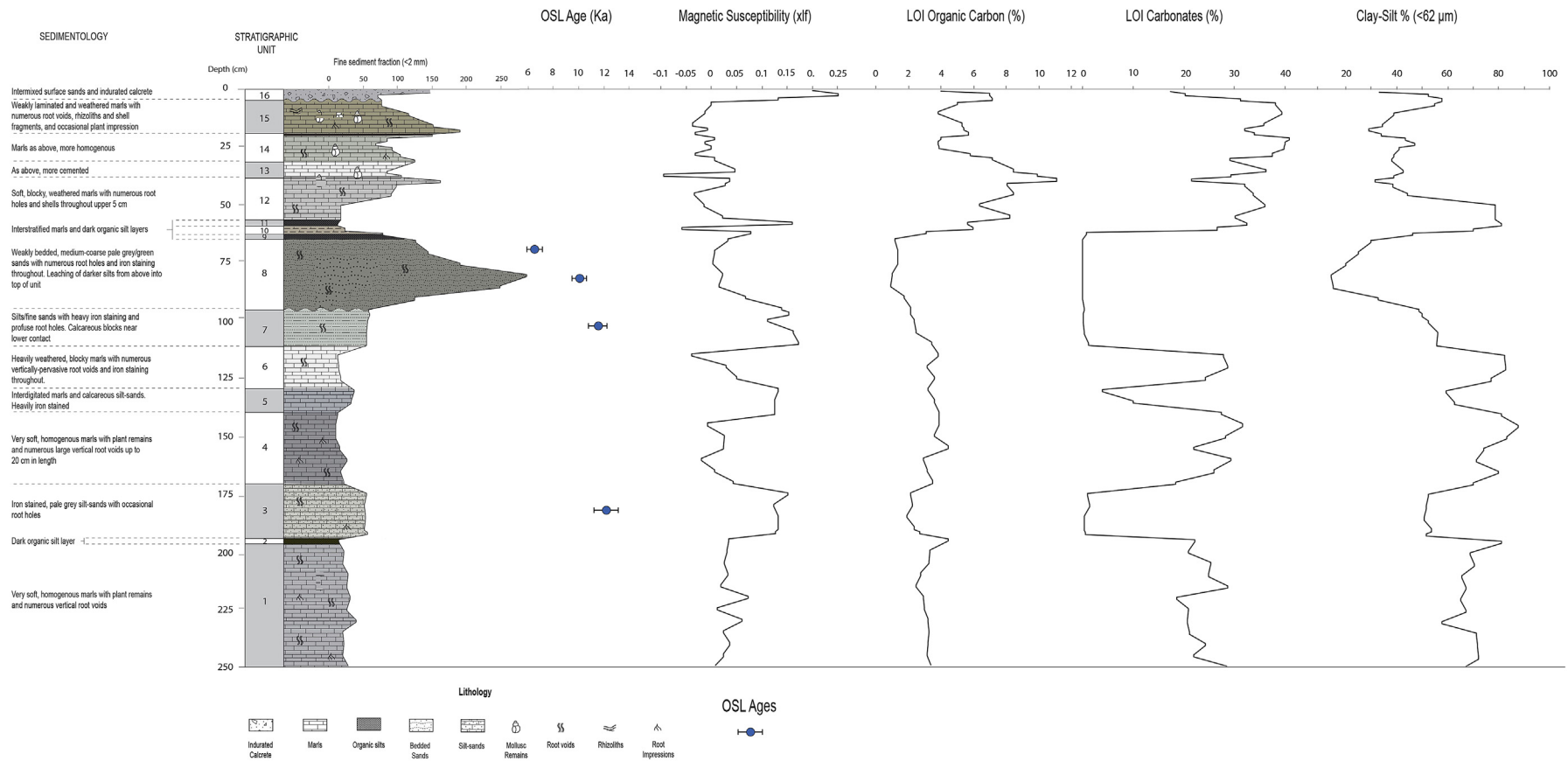


Fig. 5. Al-Rabyah section and multi-proxy stratigraphic record, showing stratigraphy of the sedimentary sequence, fine sediment granulometry (<2 mm fraction), OSL multigrain ages with errors, magnetic susceptibility values and organic carbon, carbonate and clay-silt content data.

Table 2

Elemental concentrations (relative standard error of 5%), dose rates, and final ages calculated for each OSL sample. An average water content of $5 \pm 3\%$ was assumed for dose rate calculations.

Sample	K (%)	Th (ppm)	U (ppm)	Gamma dose rate ^a (Gy ka ⁻¹)	Burial depth (m)	Total wet dose rate (Gy ka ⁻¹)	Age (ka)
ARY-OSL1	0.49	3.00	2.00	0.42 ± 0.02	0.70	1.23 ± 0.05	6.6 ± 0.7
ARY-OSL2	0.32	2.85	2.32	0.53 ± 0.03	0.87	1.25 ± 0.06	10.1 ± 0.6
ARY-OSL3	1.08	4.90	4.60	0.71 ± 0.04	1.07	2.24 ± 0.11	11.4 ± 0.8
ARY-OSL7	0.70	5.03	9.10	0.92 ± 0.05	1.10 ^b	2.71 ± 0.14	12.2 ± 1.1

^a Gamma dose rate measured on site with gamma spectrometer during dry conditions. These are corrected for average assumed water content when determining the wet dose rate.

^b Depth measured from sloping surface (see Fig. 2).

(cf. Neubert, 1998) and has not previously been reported from Holocene or Pleistocene sequences from Arabia, although it has been found in Holocene sequences in North Africa (Limondin-Lozouet et al., 2013). The Succineidae is a highly variable family of land snails and it is frequently difficult to identify species with any certainty from shell characters alone. However, succineids generally live in permanently wet places, such as marshes and the margins of lakes and rivers and many species are virtually amphibious. A single species, *Quickia* (*Quickia*) *concosa*, is known in the modern Arabian fauna (Mordan, 1988; Neubert, 1998), but this species is smaller than the specimens found at Al-Rabyah.

The non-marine ostracod assemblage (Fig. 6, Table 3) also indicates a predominantly freshwater lake environment. *Eucypris virens* is characteristic of grassy pools and ditches that dry up in late spring or summer. Both larvae and adults are resistant to

desiccation, surviving dry seasons within wet mud and reappearing with the return of wet conditions (Meisch, 2000). *Pseudocandona rostrata* is found in both permanent and temporary water bodies and *Cyclocypris ovum* is a catholic species found in almost every type of aquatic habitat, but is common in the littoral zone of lakes, temporary waters, springs and swampy habitats (Meisch, 2000). The halophyte species *Heterocypris salina* was also present; this is a Holarctic species that prefers small, slightly salty coastal and inland waterbodies (Meisch, 2000).

Taken together, these fossil assemblages are indicative of a relatively shallow waterbody surrounded by moist, well-vegetated marshland. Some species, notably the halophyte ostracod *Heterocypris salina* and the hydrobiid molluscs, suggest a degree of salinity within the Al-Rabyah lake, but none of these is necessarily indicative of strongly saline environments.

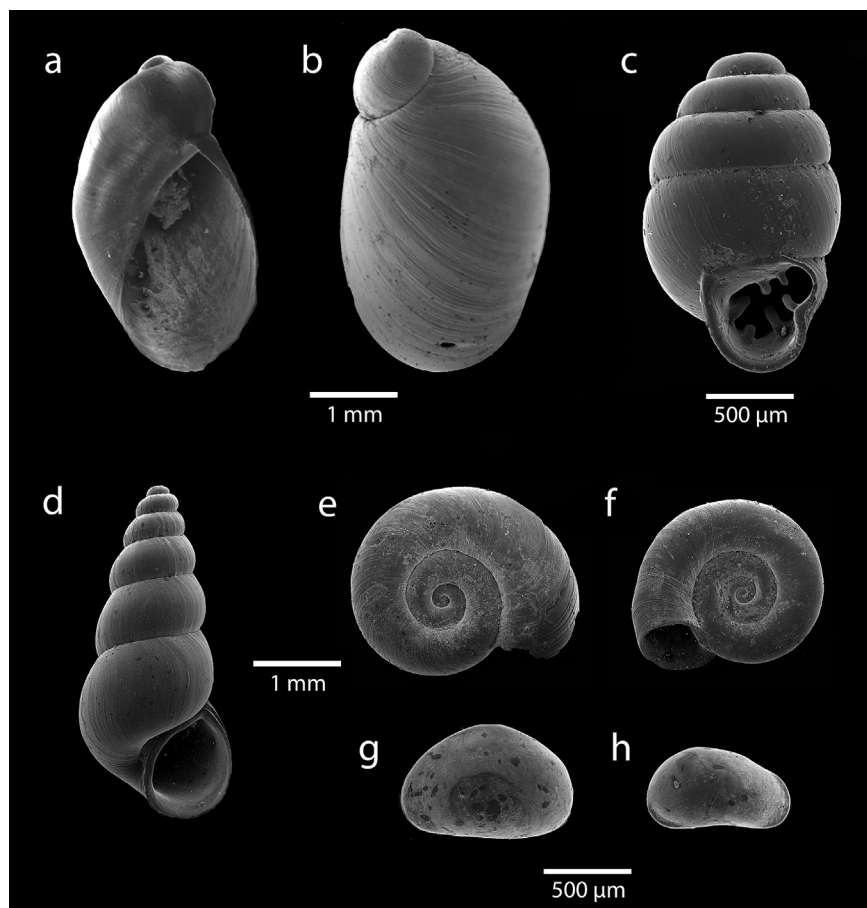


Fig. 6. Fossils recovered from the upper lake sediments at Al-Rabyah: a, b) Succineidae c) *Vertigo antivertigo* d) *Hydrobia* cf. *lactea*; e, f) *Gyraulus* sp. g) *Heterocypris salina*; h) *Pseudocandona rostrata*.

Table 3
Invertebrate fossil assemblages from the upper lake deposits (Units 9–15) at Al-Rabyah.

Freshwater Mollusca	
<i>Lymnaea</i> sp.	157
<i>Radix</i> sp.	63
<i>Gyraulus</i> sp.	31
<i>Hydrobia</i> cf. <i>lactea</i> (Küster)	8
Terrestrial Mollusca	
Succineidae	38
<i>Vertigo antvertigo</i> (Draparnaud)	24
Non-marine Ostracoda	
<i>Pseudocandona rostrata</i> (Brady & Norman)	5v, 4c
<i>Cyclocypris ovum</i> (Jurine)	1v
<i>Heterocypris salina</i> (Brady)	1v
<i>Eucypris virens</i> (Jurine)	2v
<i>Chara gyrogonites</i>	13

Table 4
Debitage from Al-Rabyah.

	n	%
Blades (complete)	5	2%
Blades (fragmented)	14	5%
Crested blades	1	0%
Bladelets (complete)	20	6%
Bladelets (fragmented)	80	26%
CTE/Debordants (complete)	28	9%
CTE/Debordants (fragments)	14	5%
Flakes	3	1%
Unidirectional parallel blade/bladelet cores	3	1%
Chips	82	27%
Chunks	54	18%
Total	116	

Heterocypris salina can tolerate entirely freshwater and so cannot be considered a reliable indicator of saline conditions unless found with other strongly halophytic species (Meisch, 2000). Both *Eucypris virens* and *Pseudocandona rostrata* have reported maximum salinity tolerances of 5‰ (oligohaline range; Meisch, 2000), providing limits on the palaeosalinity. Studies of living ostracod populations in hyper-arid regions (e.g. Mischke et al., 2012) have shown that few ostracod species can tolerate

elevated salinities approaching marine conditions, so the presence of a freshwater fauna at Al-Rabyah, with no obligate brackish species, indicates that the water body was only ever mildly saline. The life cycle of *Eucypris virens* gives an impression of the possible seasonal conditions at Al-Rabyah, since it is an early year form which spawns in the spring, after which the adults die; the eggs require full desiccation in order to develop,

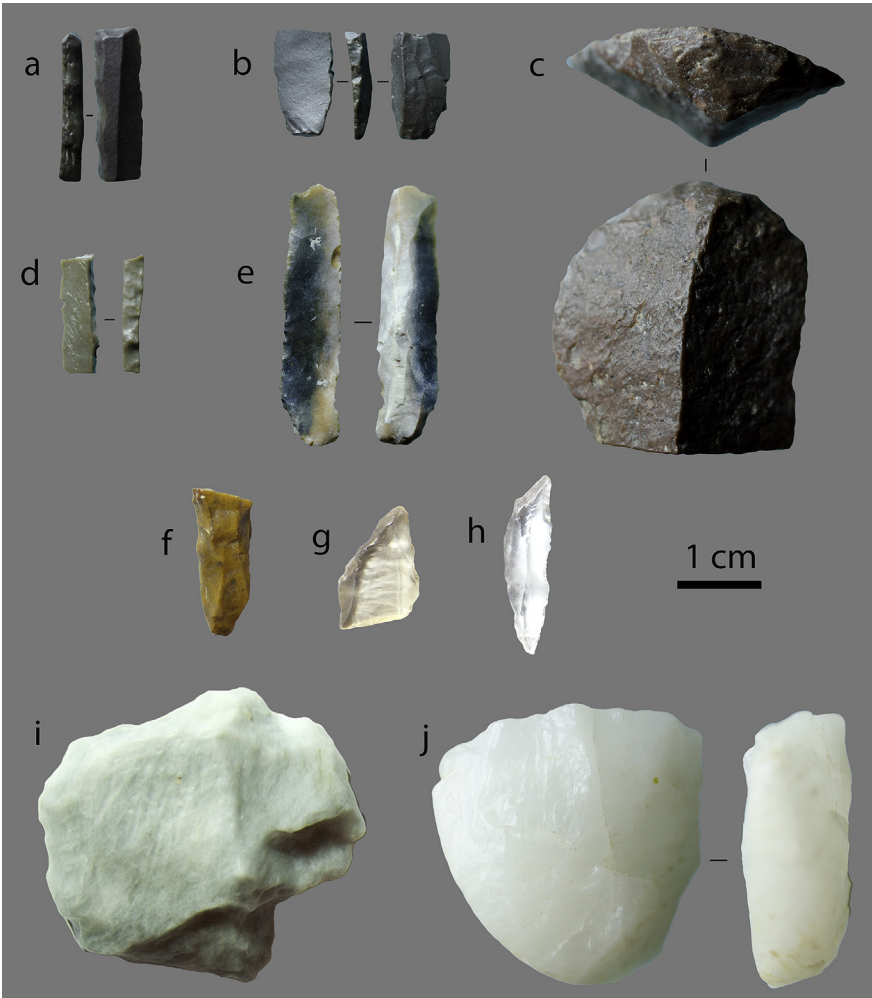


Fig. 7. Artefacts to illustrate the range of raw materials used at Al-Rabyah: a, b) dark chert; c) dark red rhyolite; d) fine-grained green silcrete; e) flint; f) yellow chert; g,h) translucent quartz; i–j) opaque quartz. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

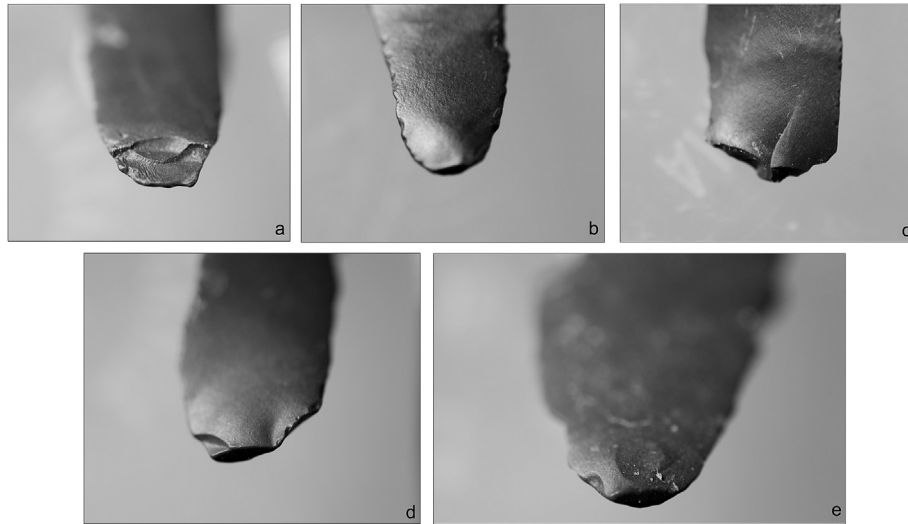


Fig. 8. Details of striking platforms on bladelets from Al-Rabyah: a) crushed striking platform; b) linear striking platform; c) pseudo-dihedral (due to fracture); d, e) flat striking platform.

with larvae reappearing when wetter conditions return in the autumn (cf. Meisch, 2000).

4.3. Artefact analyses

An assemblage of 375 lithic artefacts from Al-Rabyah was collected and analysed. These were made of a variety of fine- and coarse-grained raw materials (Fig. 7) and generally showed little evidence of abrasion or patination (cf. Schiffer, 1983; Burroni et al., 2002). Together with the low incidence of edge damage, this indicates minimal post-depositional displacement. Blank production was focused on the manufacture of bladelets (elongated blanks not wider than 12 mm) that are morphologically similar and result from a specialized blank production system. The blanks were extremely fragmented; of the 165 flakes, blades and bladelets, only 56 were complete (Table 4). Bladelets were more frequent than blades; these had a mean width of 8.3 mm, comfortably below the metrical limit used to separate the two blank types. Blades and bladelets had predominantly unidirectional parallel dorsal scar patterns, with parallel lateral edges, trapezoidal to triangular midpoint cross sections, and straight longitudinal profiles; these

characteristics are indicative of a recurrent unidirectional production system.

With the exception of two bladelets with dihedral butts, all had either punctiform or plain butts and little variability could be observed. Lipping and platform abrasion were apparent on several butts, indicating an emphasis on soft-stone hammer flaking (Pelegri, 2000; Wierer, 2013) and thorough detachment of the blanks from the cores (Fig. 8). Three cores were recovered, all of which were reduced from partially prepared striking platforms in a unidirectional parallel manner. Three artefacts merit description as *pièces esquillées* (Tixier, 1963; Demars and Laurent, 1989), although whether these pieces were the result of bipolar (on anvil) blank production or simply emerged out of a specific percussion task that required a chisel-like tool remains to be determined. The low ratio of cores to flakes suggests either a high level of reduction or transport of these artefacts away from the site.

Of the 68 tools recovered from the trench, 60.3% ($n = 41$) included backing as a major attribute; however, these could be attributed to only a few recognized types of geometric microlith (Table 5). Geometric microliths were produced on bladelets by direct percussion, and there is no evidence of micro-burin technology. Backing was administered by abrupt obverse retouch in the majority of cases. Of the 41 backed pieces, three exhibited *Ouchtata* retouch (cf. Tixier, 1963), which is semi-steep retouch of very thin edges. Only one medial fragment with straight backing showed evidence of bidirectional backing (probably produced on an anvil). Amongst the backed tools a high frequency of fragmentary pieces was observed, including straight-backed bladelet fragments, backed/truncated and backed/oblique truncated fragments. Additional backed tools found at Al-Rabyah include arched backed bladelets, trapezoids and rectangles (Fig. 9).

Backed and truncated pieces were classified based on the configuration of the truncation. The majority of these pieces ($n = 8$) were perpendicular truncations, whilst three had oblique truncations. Rectangles ($n = 3$) are extremely small (between 4.61 and 7.81 mm in width) and show transverse truncations to both the distal and proximal terminations. Two trapezoids show oblique truncations to both extremities. Arched backed bladelets and obliquely truncated bladelets are rarer and generally larger (widths between 8.36 and 9.51 mm) than the rectangles found at the site. The non-microlithic component of the Al-Rabyah assemblage is dominated by endscrapers, retouched blades and bladelets (Fig. 10).

Table 5

Total tool count from Al-Rabyah.

	<i>n</i>	%
Retouched bladelets	5	7%
Retouched blades	5	7%
Partially retouched blanks	3	5%
Notches	3	5%
Endscrapers	8	12%
Multi function/composite tools	2	2%
Transverse scrapers	1	1%
Microliths and geometrics:		
Backed and truncated bladelets	8	12%
Straight-backed bladelets	22	32%
Backed and obliquely truncated bladelets	3	5%
Rectangles	3	5%
Trapezoids	2	2%
Arched backed bladelets	3	5%
Total:	68	

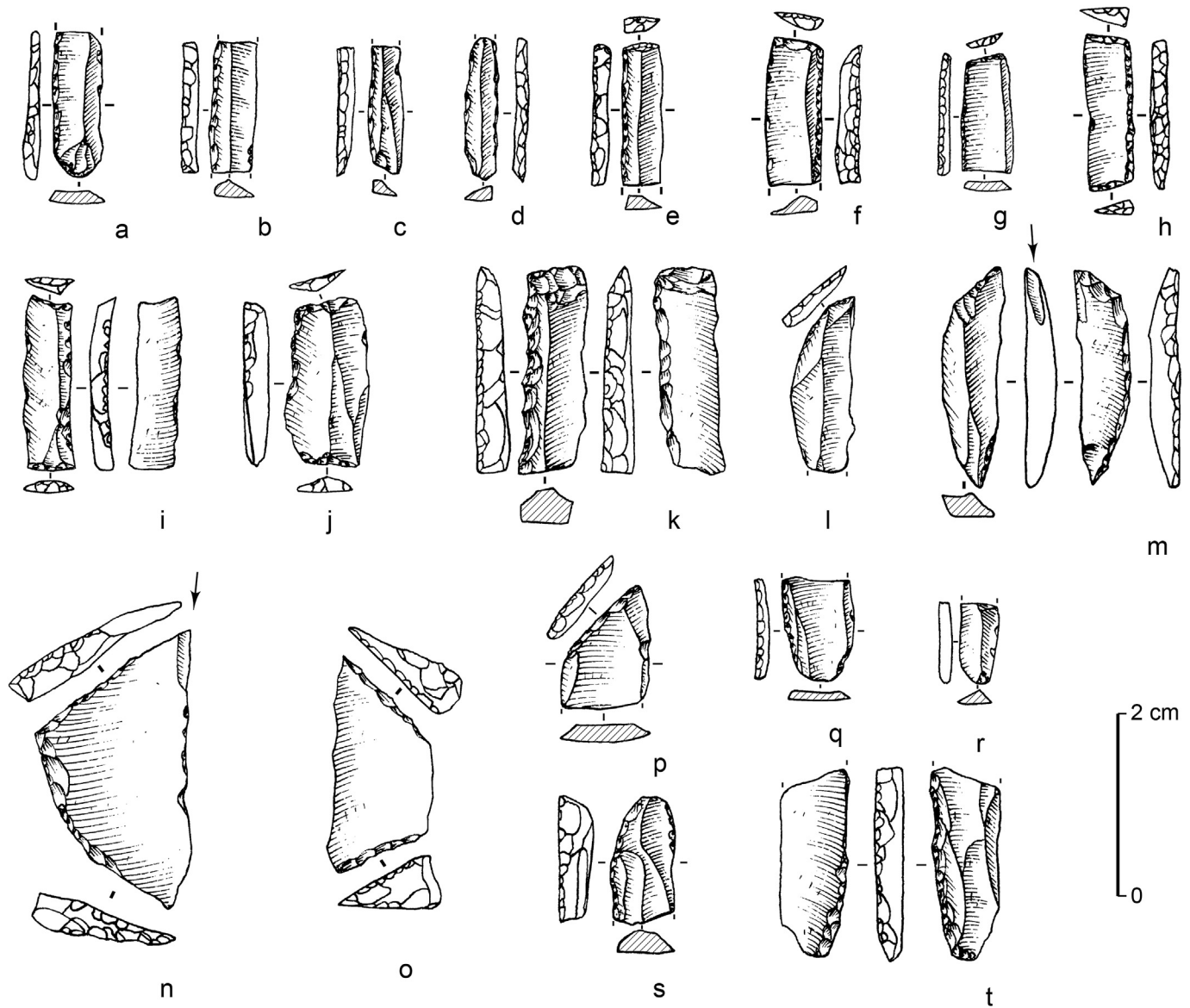


Fig. 9. Lithics from Al-Rabyah: a–d) straight backed bladelets; e–g) straight backed and truncated bladelet fragments; h–k) rectangular geometric microliths; l) bladelet with oblique truncation; m) straight inversely backed bladelet with oblique truncation and impact fracture; n–o) trapezoidal geometric microliths; p) bladelet fragment with oblique truncation; q) bladelet fragment with Ouchtata retouch; r) bladelet fragment; s) arched backed bladelet fragment; t) straight backed bladelet with additional inverse retouch to base.

In addition, a fragment of a thin sandstone disc was recovered from Unit 8 (Fig. 11). The surface of this object had been smoothed into a desired shape and it represents the only non-knapped artefact from Al-Rabyah.

5. Discussion

The chronostratigraphic and palaeoenvironmental records from Al-Rabyah provide an important framework for understanding human occupation of the southern Nefud desert during the Terminal Pleistocene–Early Holocene. The lithic assemblage exhibits some similarities with the reduction strategy of the Geometric Kebaran (GK), an industry best known from sites in the Levant dated to the period between 18.0 and 14.7 ka (Garrard and Byrd, 2013; Shea, 2013). The GK is characterized by its propensity towards the production of geometric microliths (e.g. Bar-Yosef, 1970; Marks, 1976; Goring-Morris, 1978, 1995; Coqueugniot and Cauvin,

1988; Shimelmitz et al., 2004), with blank production focused on bladelets; these are produced from unidirectional pyramidal bladelet cores and are uniform in their morphology and metrics (Bar-Yosef, 1980; Henry, 1982; Goring-Morris, 1995). GK assemblages also include ground stone artefacts including small limestone or sandstone discs analogous to the specimen found at Al-Rabyah (Wright, 1994; Goring-Morris, 1995).

However, although the techno/typological appearance of the Al-Rabyah assemblage is in keeping with those of the GK, the much younger dates mean that it is difficult to establish a direct connection between Levantine populations and those in the southern Nefud. Nonetheless, given the chronological range of the Levantine EP of between ~24.0 and 11.6 ka (Belfer-Cohen and Goring-Morris, 2002; Shea, 2013) and the typological variation of these industries, the date of the earlier lacustrine deposits at Al-Rabyah (before 12.2 ka) invites comparison with Levantine assemblages. It has been suggested that the GK may have spread into

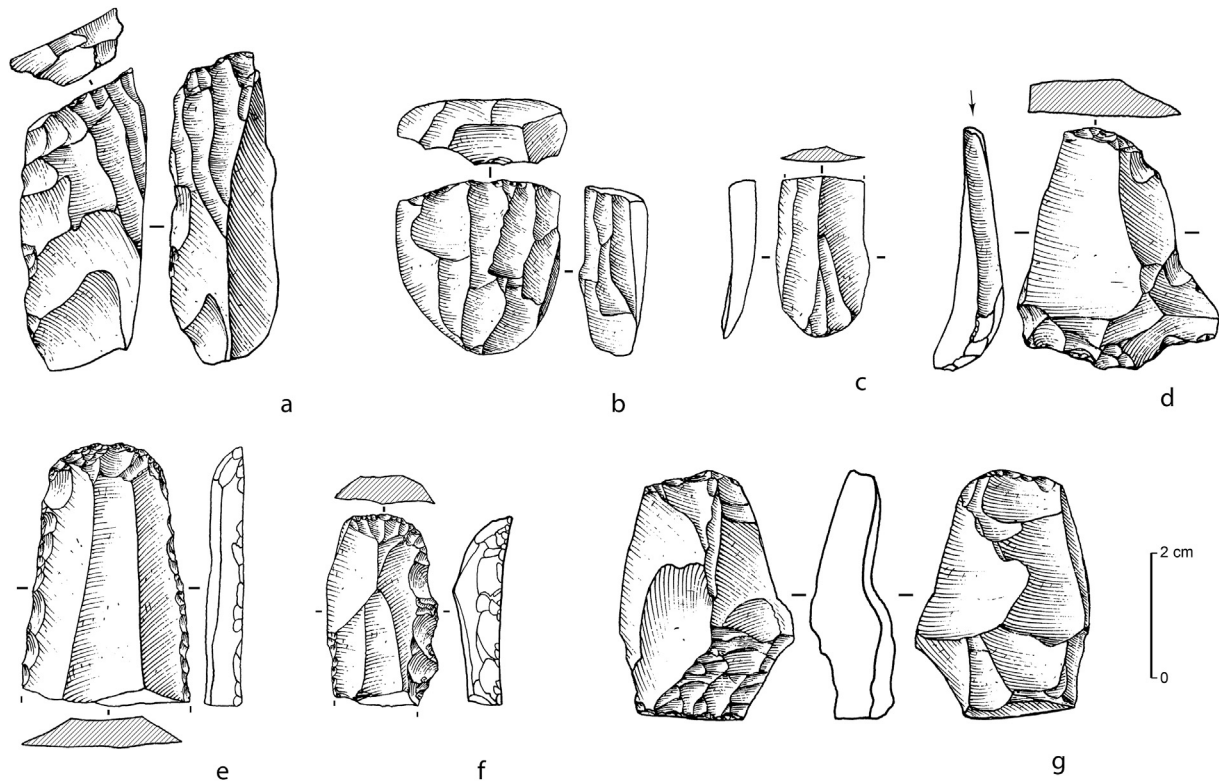


Fig. 10. Lithics from Al-Rabyah: a–b) bladelet cores; c) proximal blade fragment; d) combination tool burin and double endscraper; e–f) endscrapers with additional lateral retouch; g) *pièces esquillées*.

previously (semi)arid regions at around ~14.7–12.7 ka (cf. Goring-Morris et al., 2009; Maher et al., 2011). Indeed, undated GK sites in the Negev and Sinai desert, such as D5, Ma'aleh Ziq and Wadi Sayakh (Marks, 1976; Goring-Morris, 1978; Bar-Yosef and Killebrew, 1984) might represent interaction with other late EP populations (Goring-Morris, 1987; Henry, 1997). It is therefore possible that

lithic industries related to the GK persisted beyond both the chronometric and geographical ranges of its 'core' Levantine region. Climatic deterioration at around 12.8–11.5 ka might have isolated the southern Nefud from the Levant, interrupting further cultural and/or demographic transmission between the two areas, resulting in the development of lithic industry with both Levantine EP and local traits within the Jubbah basin. A similar cultural transmission seems to have occurred during a subsequent phase of humid climate, when re-connection of the southern Nefud and the Levant allowed incorporation of projectile point forms typical for the Near Eastern PPNB and PPNB into the local archaeological record (cf. Crassard et al., 2013).

The lithic assemblage from Al-Rabyah was recovered from within Unit 8, although it is likely to pre-date this deposit and probably relates to the earlier wetter phase represented by underlying sediments (Fig. 5). However, palaeoenvironmental evidence from Unit 8 suggests that the environment within the Jubbah basin remained wet enough to support vegetation throughout this period. Although lakes within the basin were probably in retreat (or even largely absent) at that time, groundwater was persistently present and the environment remained conducive to human exploitation. A mechanism for this is provided by the extensive dune fields that surround the Jubbah basin, which generate negligible surface runoff and therefore absorb and recharge meteoric waters directly into the basin, even during relatively dry periods when rainfall was insufficient for lake formation. The situation at Jubbah can be contrasted with the Tayma basin, located ~250 km to the west, which occupies an area of low relief with shallow sedimentary cover. Here, the onset of Holocene lake formation has been radiocarbon dated to between ~10 and 9 ka (Engel et al., 2012). The shallow nature of the Tayma basin, coupled with the absence of large dunefields in the surrounding area, meant that the lake here contracted after ~8.5 ka and the residual waters became



Fig. 11. Polished sandstone disc characteristic of Levantine Epipalaeolithic industries, recovered from Unit 8 at Al-Rabyah.

increasingly saline (Engel et al., 2012; Ginau et al., 2012). The much greater depth of the Jubbah basin, where several wells located at the centre of the basin have proved up to 40 m of sediments, provides significantly more accommodation space allowing successive phases of lake formation. Numerous relict landforms indicative of past wetter climates are exposed across the basin floor; as ~10 m deep stratified lacustrine sequences exposed at modern quarry sites, as perched interdunal lake marls adjacent to large jebels, and as exposed mesas in peripheral areas. Moreover, the topographic setting of the Jubbah basin means that only minimal rainfall was required for groundwater recharge. Indeed, palaeohydrological findings from palaeolake Tayma indicate that just 150 ± 25 mm annual precipitation was sufficient to sustain a perennial freshwater lake (Engel et al., 2012), whilst studies from the Dhana region have shown that just 50 mm of rainfall on typical Nefud dunes is sufficient for aquifer recharge (Dincer et al., 1974). Both the Tayma and Jubbah basins have exhibited near-surface groundwater until recent times (Garrard et al., 1981). Analyses in neighbouring regions have suggested that monsoonal rains did not reach northern Arabia during the Early to Mid-Holocene, but rather moisture was derived from Mediterranean Westerly air masses (Arz et al., 2003). There is therefore a strong possibility that similar systems were responsible for the Terminal Pleistocene–Early Holocene rainfall across the Levant and southern Nefud.

The Jubbah basin therefore represented a critical oasis within the southern Nefud during the Terminal Pleistocene–Early Holocene (~12–10 ka), at a time when other regions within central and northern Arabia were apparently experiencing much drier environmental conditions (cf. Vaks et al., 2010; Enzel et al., 2008; Petit-Maire et al., 2010). Palaeoclimatic records from the Near East indicate that the timing of lake formation at Al-Rabyah coincides with the onset of aridity in regions typically associated with EP industries, which may reflect contrasting climatic regimes between the Levant and the southern Nefud. Critically, the dated Al-Rabyah sequence underpins an emerging picture of local environmental conditions across the southern Nefud, characterised by wetter environments in the Jubbah basin throughout the Early Holocene (cf. Whitney et al., 1983; Schulz and Whitney, 1986; Engel et al., 2012; Crassard et al., 2013). These conditions would probably have supported a substantial biomass, attracting both animals and humans from surrounding arid regions.

6. Conclusions

The site at Al-Rabyah is the first dated Epipalaeolithic site in Arabia, and is therefore a key locality for understanding human occupation during the Terminal Pleistocene–Early Holocene. The palaeoenvironmental record indicates that shallow lakes formed in the Jubbah basin twice during this period, the first occurring during the last part of the Terminal Pleistocene prior to $c. 12.2 \pm 1.1$ ka, and the second after 6.6 ± 0.7 ka. The timing of these wetter phases appears to be incongruous with records from elsewhere in Arabia, southern Jordan and the Negev, where the climate appears to have been more arid. In addition, sedimentary evidence indicates that the Jubbah basin probably continued to receive significant groundwater recharge during periods of increased aridity due to its location within a major dunefield, and therefore represented an important oasis at various times during the Terminal Pleistocene–Early Holocene.

The archaeological assemblage is dominated by trapezoid and rectangular geometric microliths, with a high frequency of backed and truncated pieces. These were manufactured without the use of the microburin technique, and the technological scheme for blanks is dominated by the production of bladelets through recurrent unidirectional-parallel soft-stone hammer flaking. These features

are similar to Levantine EP industries, although the dating evidence shows that they are significantly younger than these assemblages, making direct comparison difficult. Although a local independent origin of this technology cannot be ruled out, we suggest that the presence of an assemblage with Levantine Epipalaeolithic affinities in the Arabian interior is due to the prolonged presence of a freshwater oasis in the Jubbah Basin during the Terminal Pleistocene–Early Holocene. Indeed, the presence of Middle Palaeolithic, Epipalaeolithic and Pre-Pottery Neolithic assemblages within the Jubbah basin indicate recurring demographic and/or cultural exchanges between the Levant and northern Arabia, although establishing the extent to which these were dependent on regional climatic and environmental factors requires further research.

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